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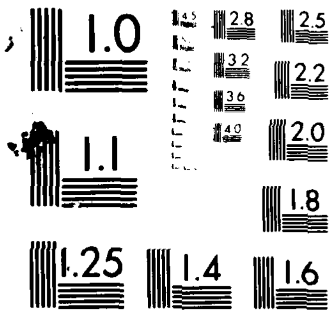

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REPORT SD-TR-81-108

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Observation of Field Aligned Ion and Electron Beams from SCATHA (P78-2)

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25 February 1982

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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusion. It is published only for the exchange and stimulation of ideas.

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Intense field-aligned beams of ions and electrons have been observed by electrostatic analyzers on the SCATHA (P78-2) satellite. The beams have peaked energy spectra with energies ranging from tens of eV to several keV. These beams show a strong local time dependence, with occurrence frequencies peaking near local midnight. The occurrence frequencies of these beams are also positively correlated with Kp. Comparisons have been done with S3-3 observations of field-aligned ion fluxes, suggesting a direct relationship

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19. KEY WORDS (Continued)

20. ABSTRACT (Continued)

between acceleration of ions at low altitude in the auroral region and the observations of field aligned beams at the equator near synchronous orbit.

PREFACE

We would like to thank D. Gorney, P. Mizera, R. Strangeway and R. Johnson for many helpful discussions. The S3-3 portion of this work was supported by the National Science Foundation under grant ATM-8000518.

A

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FIGURES

Introduction

Intense fluxes of upflowing ions have been observed at high latitudes near the Earth by the polar orbiting satellites S3-3 and Isis (Shelley et al., 1976; Sharp et al., 1977; Mizera and Fennell, 1977; Klumpar, 1979; Ungstrup et al., 1979). Two basic types of upflowing ion events have been observed; ion beams have a peak in flux along the magnetic field direction, while ion conics show two flux peaks positioned symmetrically around the magnetic field direction with a relative flux minimum in the field direction. Statistical studies have been done correlating the presence of field aligned ion distributions with local time,latitude, altitude, energy, and Kp index (Ghielmetti et al., 1978; Gorney et al., 1981). These studies concluded that the upflowing ion events coincided with the statistical auroral oval of Feldstein et al. (1969), were positively correlated with Kp, and displayed a strong maximum in occurrence frequency in the evening local time sector. Ghielmetti et al. (1978) were able to determine the composition of these events and found that about half the events consisted predominantly of protons and half of O^+ ions.

Field-aligned ion distributions have also been observed near the equator in the outer magnetosphere at geosynchronous altitudes (Horwitz and Chappell, 1979; Cormfort and Horwitz, 1980; Horwitz, 1980; Fennell et al., 1981; Singh et al., 1981). Horwitz (1980) has done a statistical study of conical distributions observed by ATS-6 at geosynchronous orbit. He finds that conics occur at all local times with a maximum occurrence frequency near dusk, with flux peaks generally occurring at pitch angles between 15° and 35°. It is not clear that these high-altitude conics result from the same processes as the conics observed by the S3-3 satellite.

Intense fluxes of electrons moving both parallel and anti-parallel to the magnetic field have been reported at low altitudes (~ 1 R_E) over the auroral zone by Sharp et al. (1980). These counterstreaming electron beams were often associated with ions with conical or broadly peaked pitch angle distributions and occurred during disturbed times. Electron beams have also been observed at geosynchronous orbit near the equator (McIlwain, 1975; Borg et al., 1978).

The Aerospace Corporation has flown ion and electron electrostatic analyzers aboard the SCATHA (P78-2) satellite. This is a spin stabilized satellite in a near-equatorial orbit with apogee at 7.8 R_E and perigee at 5.3 R_E. The orbital period is slightly less than 24 hours so that the satellite has an apogee drift of about 5° eastward in geographic longitude per day. The spin axis is in the orbital plane and is approximately normal to the Earth-sun line. The view direction of the Aerospace particle detectors is perpendicular to the spin axis allowing a fairly complete angular distribution to be measured during every 57 second spin period. These detectors can measure a 21 channel energy spectrum every three seconds with an energy range of 18 eV to 19.4 KeV for electrons and 17 eV to 15.6 KeV for protons.

The purpose of the present study is to provide a preliminary statistical survey of ion and electron beams observed at the equator from SCATHA. Comparisons will be made between our study of equatorial beams and previous studies of low altitude beams. We also compare data from the S3-3 and SCATHA satellites on the few days for which we have simultaneous data.

This is by necessity a preliminary study based on the 21 days worth of SCATHA data we currently have processed, and will be extended in the future. The data set we use here is biased in that for all 21 days of data the satellite apogee is in the morning local time sector.

Data

For the purposes of this study a field aligned beam is defined as a distribution having a peak in flux at a non-zero energy oriented ~ 0° or ~ 180° to the magnetic field direction. Due to magnetic focusing, limited angular resolution, and incomplete pitch angle scans it is generally not possible to distinguish between field aligned ions which originated at low altitudes as beams or conics, and no attempt is made here to do so. Conics of the type reported by Horwitz (1980) at the equator with flux peaks at 15° - 35° pitch angle can be resolved and are not included in this study.

Figure 1 shows some examples of the ion and electron beams observed. The plots on the left of each panel are distribution function contours plotted in velocity space, with 180° pitch angle to the left and 0° to the right. The plots on the right are the corresponding energy spectra for 0°, 90°, and 180° pitch angle particles. The top panel shows an example of an ion beam moving toward the equator at a pitch angle of 0° with a peak flux at about 250 eV/q. The bottom panel shows an example of counterstreaming electron beams. From the energy spectra it is apparent that the electron flux peaks at about 100 eV at both 0° and 180° pitch angle. These beams are usually observed to persist over many spin periods.

Figure 2 is an energy versus time spectrogram containing both ion and electron beams. Electrons are shown at the top with energy increasing upwards; ions are on the bottom with energy increasing downwards. The brightness of the plot is proportional to the measured particle energy flux at each point. The blank areas beginning at 60250 and 61250 sec. UT are times when the instruments were off. Electron beams are visible between 59400 and 60250 sec UT and again from 60900-61250 UT. These electron beams are counterstreaming at 0° and 180° to the magnetic field with energies of up to a few

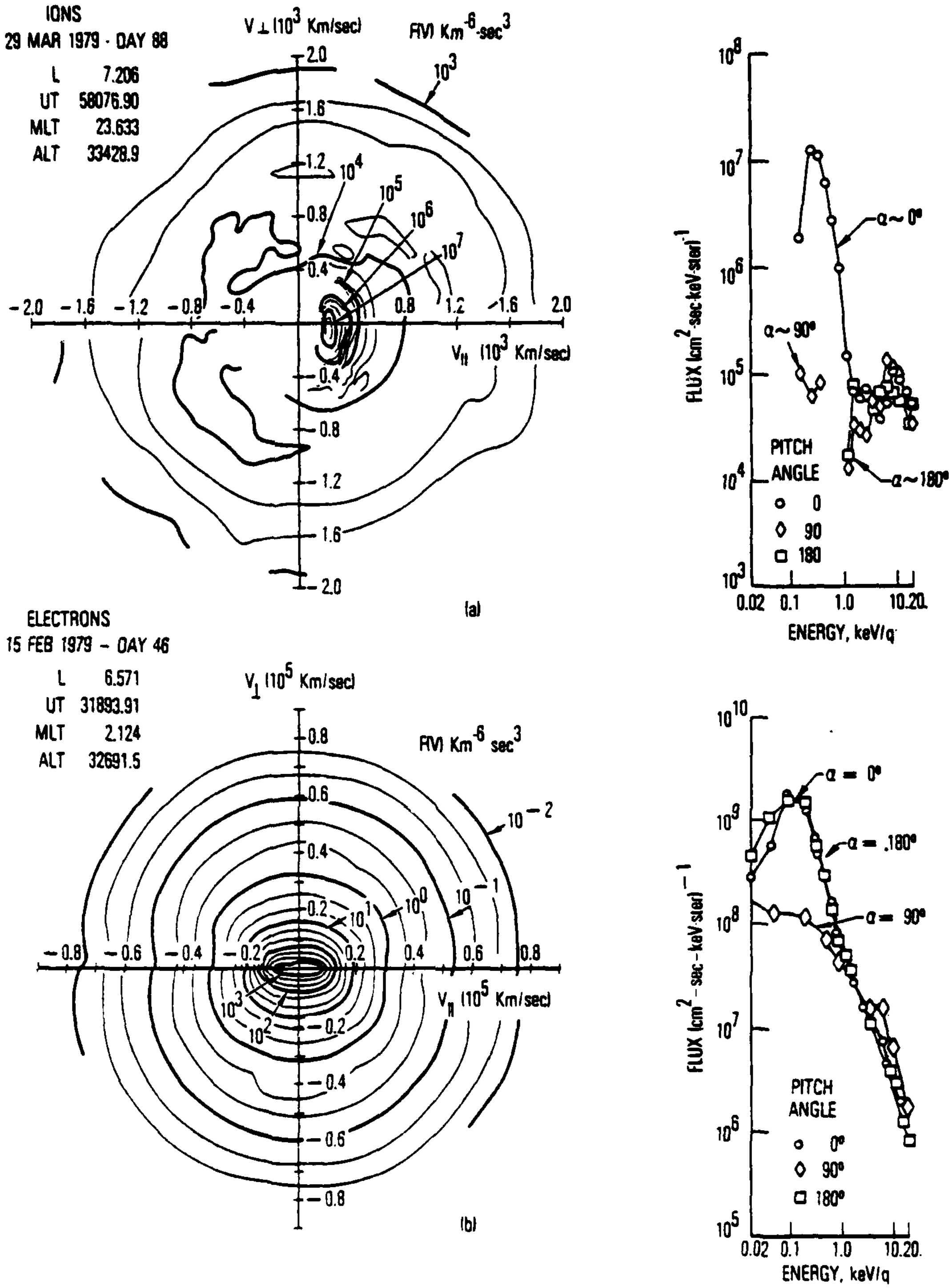

Fig. 1. Two typical ion and electron distributions containing field aligned beams. The left plots show isodistribution contours in velocity space. Energy spectra (flux vs energy) parallel and perpendicular to the magnetic field are shown at the right.

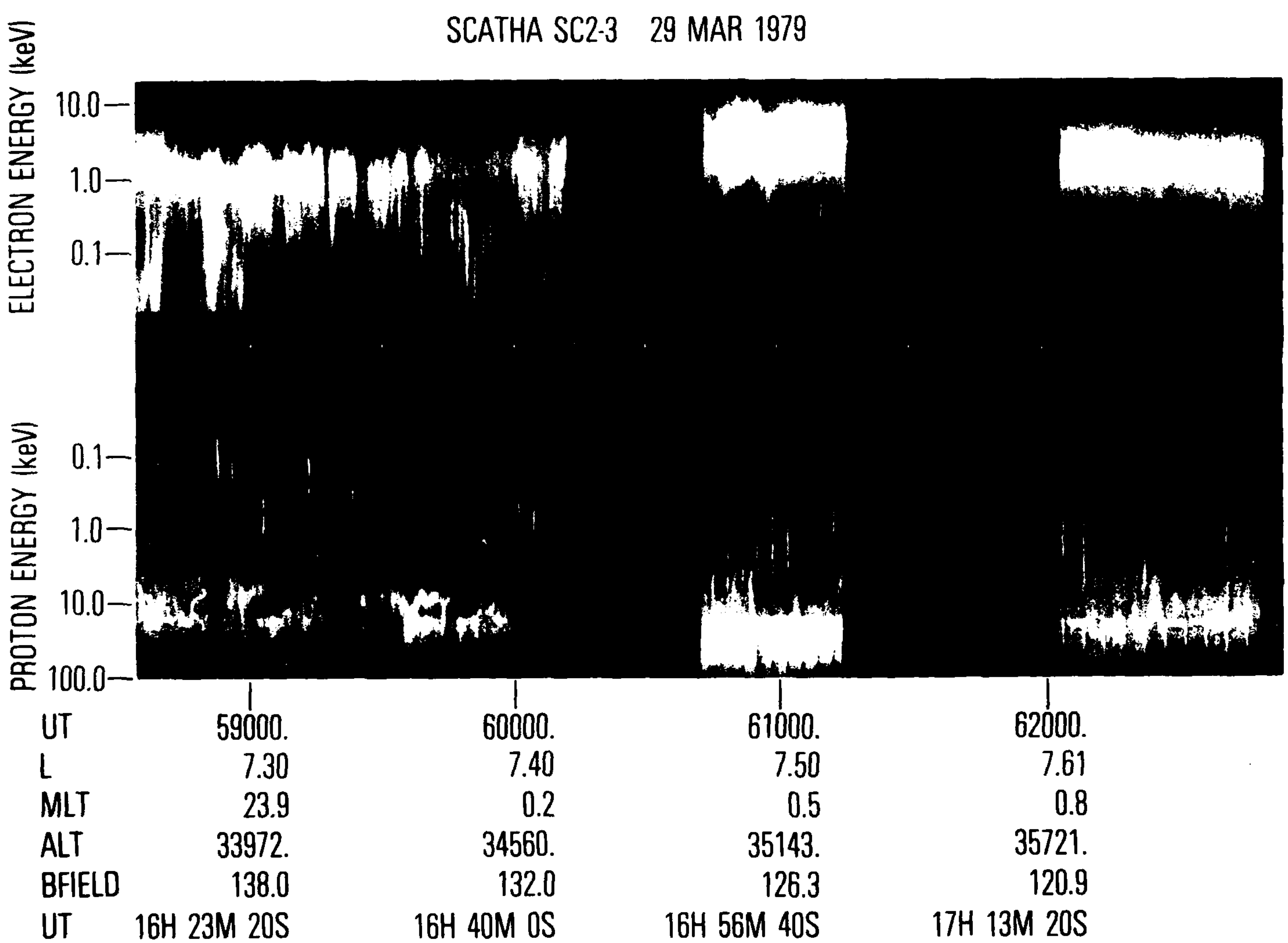

Fig. 2. Spectrogram showing electrons (top) and ions (bottom) on March 29, 1979. Ion beams are visible all across the plot, electron beams are seen from 59000 to 60150 UT and from 61000 to 61250 UT.

hundred eV. Ion beams of varying energy are visible all across the spectrogram. These ions are moving only parallel to the magnetic field and in this case toward the equator, except near 60800 UT where the ion beams are observed to be counterstreaming. Note that although the ion beams show up on the spectrogram as spikes once a spin period when the detector is looking along the field direction, ions are continuously streaming parallel to the field lines throughout this region.

We will call a block of time filled with 0° and/or 180° beams as in Figure 2 a beam event. Ion beam events last anywhere from 7 minutes to 5 hours, with an average duration of about an hour and standard deviation $\sigma = 65$ minutes. For the longest ion beam event beams are continuously observed as the satellite moves through 6 hours of local time and in radial distance from L=5.7 to L=7.1. Electron beam events persist for a much shorter time, their average length being 27 minutes with $\sigma = 20$ minutes. Ion beam events also occur much more frequently than electron beam events. In the 21 days of data analyzed 26 separate ion beam events were observed as compared to only 11 such electron events. When electron beams do occur they are usually associated with ion beams (as in Fig. 2). Six of the 11 electron beam events observed occur during an ion beam event and the remaining 5 just before the onset of ion beams.

Examples of counterstreaming electron beams have been shown in Figs. 1 and 2. Electron beams were always observed to be counterstreaming. Counterstreaming ion beams are also observed (as in Fig. 2). About half of the ion beam events consist of counterstreaming beams, the rest consist of beams moving only parallel or only anti-parallel to the magnetic field direction. The beam direction is usually consistent within a beam event; if a beam event starts out with counterstreaming beams then the beams counterstream throughout the event and the same holds true for unidirectional beam events.

Figure 3a shows the available coverage of local times and L shells. The L values are obtained using a 1976 version of the Olsen-Pfitzer model field which includes the dipole tilt and seasonal effects (Olsen and Pfitzer, 1976), and corresponding latitudes of the feet of the field lines are calculated using $\cos^2 \Lambda = 1/L$ where Λ is invariant latitude. A latitude-time bin was considered to be covered by an orbit if any part of the orbit was spent inside the bin. Since the satellite apogee was in the morning sector we have better coverage for higher latitudes in the morning and lower latitudes in the evening. Figure 3b shows the distribution of ion beams in the same bin system. The occurrence frequency of ion beams, defined as the fraction of passes through each bin in which at least one beam is observed, increases with latitude from .08 for $\Lambda = 64-66^\circ$ to .18 for $\Lambda = 68-70^\circ$ In local time the occurrence frequency peaks near local midnight at all Λs.

The distribution of ion beams in energy is shown in Fig. 4. The beams have been divided into logarithmically equal energy bins; the number of beams with flux peaking in each bin is plotted. There is a broad maximum in ion beam energies centered at about 250 eV. Beams with energies up to about 8 keV are seen.

The correlation of ion beam events with the Kp index is shown in the top panel of Figure 5. The occurrence of ion beams seems to be positively correlated with Kp, the percentage of 3 hour periods containing beams increases from < 2% for Kp = 0 and 1 to 75% for Kp = 7. The bottom two graphs of Fig. 5 subdivide the beam events by energy into two groups, those with energy greater than and less than 256 eV. Higher energy beams occur most frequently when Kp is high, while the lower energy beams occur when Kp is 2 - 4.

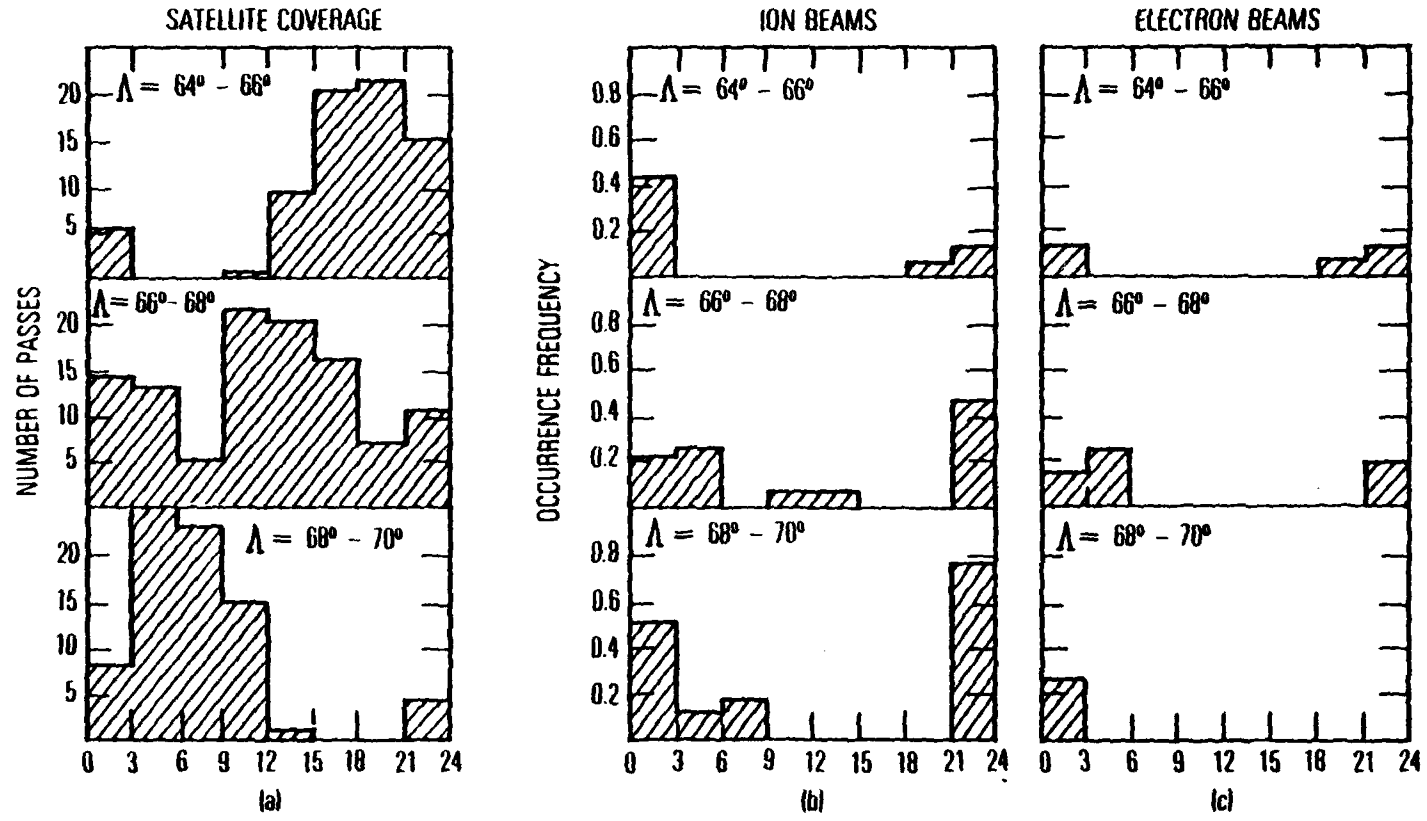

Fig. 3. a) Available coverage of latitudes (or L-shells) and local times from SCATHA. b) Location of ion beam events in latitude and local time. c) Location of electron beam events in latitude and local time.

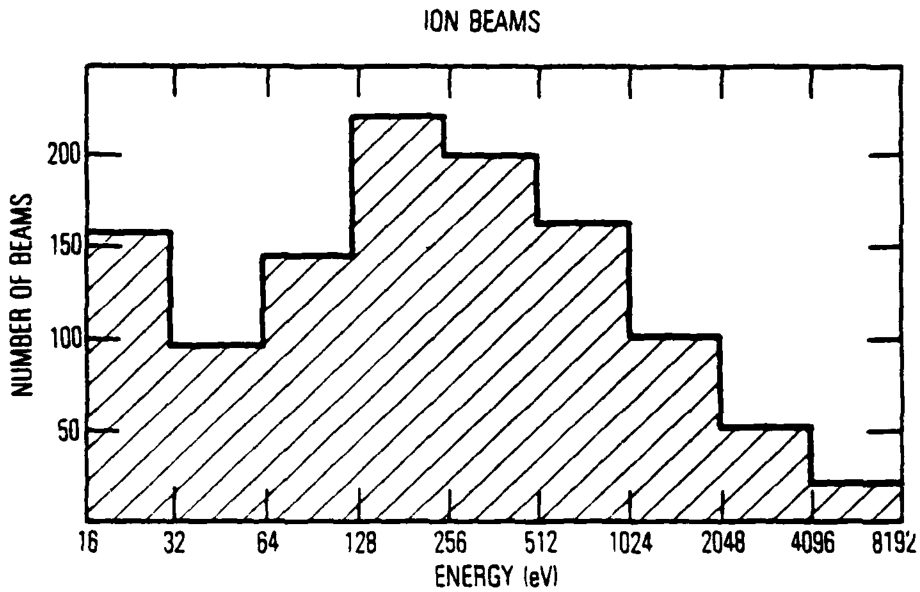

Fig. 4. Distribution of energies of ion beams.

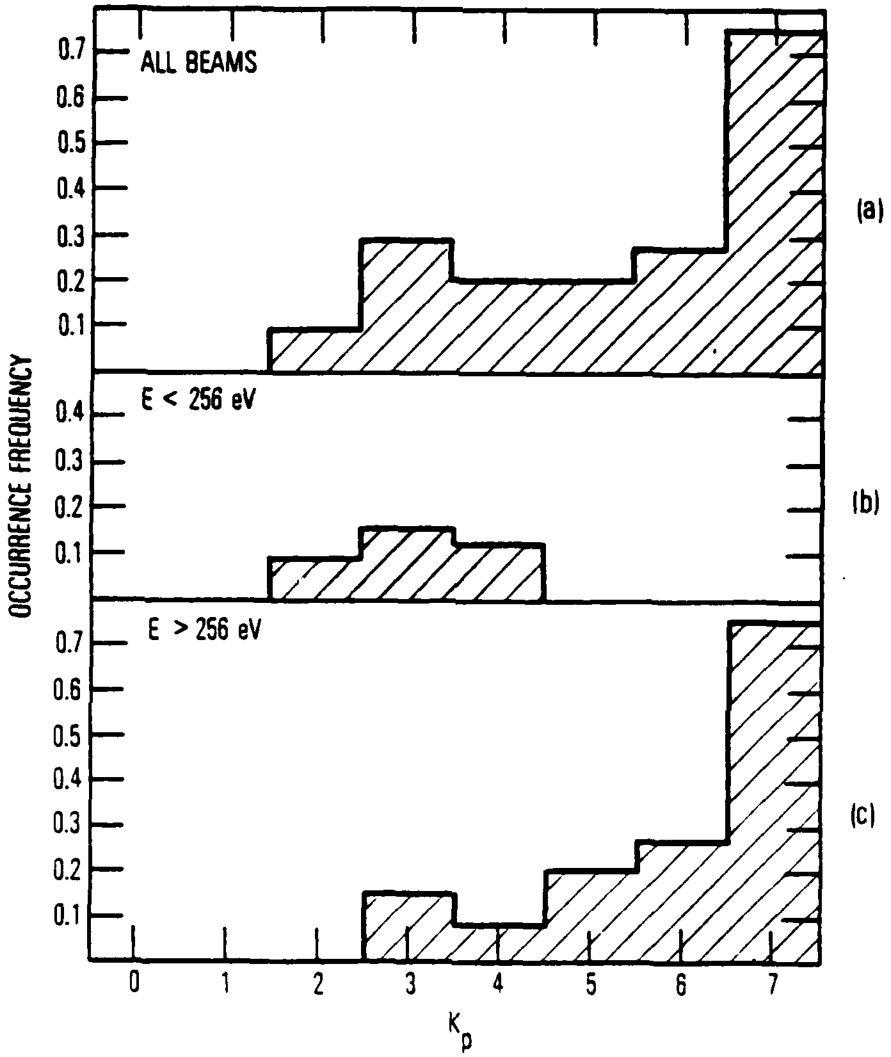

Fig. 5. Occurrence frequency of ion beam events. (a) Fraction of 3-hour periods containing a beam event as a function of Kp. (b) Occurrence frequency of ion beam events with average beam energy greater than 256 eV as a function of Kp. (c) Occurrence frequency of ion beam events with average beam energy less than 256 eV as a function of Kp.

The same statistics have been done for electron beams. Fig. 3c shows the locations of electron beam events with respect to latitude and local time. Their occurrence frequency, like the ions, is peaked near midnight but there is no obvious latitude dependence. No electron beams were observed from 6 to 18 hours local time. The energy distributon of electron beams is shown in Fig. 6. The mean energy is about 100 eV, less than that for ion beams, and there are few electron beams with energies greater than 1 keV. The occurrence of electron beams is also positively correlated with Kp; no electron beams are seen unless Kp > 3.

Both ion and electron beams are seen only when the satellite is in the plasma sheet. They are often associated with (occur just before, just after, or simultaneously with) injection events. Fourteen of the 26 ion beam events and 7 of the 11 electron beam events are associated with injections of energetic electrons.

The composition of two of the ion beam events observed have been determined by the Lockheed ion composition experiment aboard SCATHA (R. Strangeway, private communication). In both of these cases the ion beams were composed primarily of oxygen ions. We are in the process of doing intercomparisons for other ion beam events.

Discussion and Summary

The equatorial beams observed by SCATHA can be compared with the low altitude beams observed by S3-3. Ghielmetti et al. (1978) find that the latitudinal distribution of upflowing ions is a function of local time, with the peak moving from $\Lambda \sim 78^{o}$ at noon to $\Lambda \sim 68^{o}$ at midnight. To compare these S3-3 results with those given here it is necessary to look at latitudes between 64° and 70° where SCATHA orbits. At these latitudes the local time

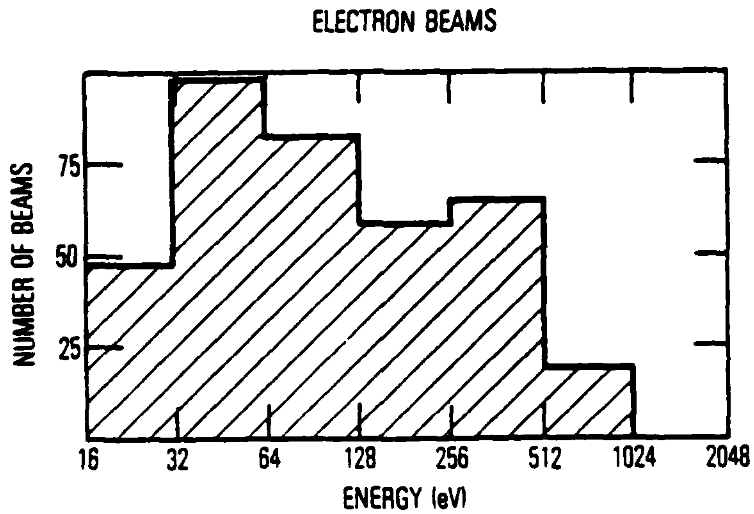

Fig. 6. Distribution of energies of electron beams.

distribution of beams and conics observed by S3-3 peaks between 21 and 24 hours, consistent with the peak near midnight observed by SCATHA. Gorney et al. (1981), using S3-3 data, found that soft (<400 eV) beams occur more frequently than hard (>2 KeV) beams and that the energy and frequency of beams increases with K_p, in agreement with SCATHA observations.

The half width of beams observed by SCATHA ranges from 10°-45°. This indicates that scattering must occur if these beams are of low altitude origin, since magnetic focusing would otherwise restrict these beams to half widths of less than 5°. Ion cyclotron waves are observed to be associated with ion beams (Kintner et al., 1979; Gorney, private communication, 1981) providing a possible mechanism for this scattering. Ghielmetti et al. (1979) have concluded on the basis of a study of downflowing ions that strong pitch angle scattering does occur within a bounce period.

The flux $(cm^2 - sec - keV - ster)^{-1}$ of ions in the beams observed by SCATHA and S3-3 can be compared. In the absence of pitch angle scattering the fluxes measured anywhere along a flux tube should be the same, since the increase in flux tube area is balanced by the decrease in the width of the beam. Pitch angle scattering does occur, however, with the result that the beams observed by SCATHA have approximately the same widths as those observed by S3-3. The fluxes measured by SCATHA should therefore be less than those observed by S3-3 by a factor of A_{eq}/A_{S3-3} (A is the area of the flux tube) or, since BdA = constant, by the ratio B_{eq}/B_{S3-3} which varies between ~ 1/50 to 1/400 over S3-3's orbit. Comparisons of typical measured fluxes on S3-3 and SCATHA are consistent with these beams being the same phenomena.

There are five days on which S3-3 data is available at the same time as ion beams were observed from SCATHA. On three of these days ion beams were seen at the same UT and at about the same latitude by both satellites but at different local times. On one day S3-3 observed ion beams at the same local time and latitude as SCATHA but 2000 sec later in UT. In the other case ion beams were seen by SCATHA but not by S3-3 although the field model predicted both satellites were simultaneously at the same latitude and local time. The mapping procedure, using a quiet time field model during a relatively disturbed time, could account for this one apparent failure of our hypothesis that the equatorial ion beams originate from low altitudes in the auroral zone.

We have shown that the ion beams observed by SCATHA are consistent with these beams coming from the auroral region, where they are interpreted as being formed by acceleration in a quasi-static electric field parallel to the magnetic field lines (Mizera and Fennell, 1977; Sharp et al., 1977; Croley et al., 1978) or by perpendicular heating at low altitudes and subsequent magnetic focusing as they move up the field lines (Sharp et al., 1977; Klumpar, 1979; Ungstrup et al., 1979; Comfort and Horwitz, 1980).

The origin of the electron beams is unknown. The counterstreaming electron beams observed at an altitude of 1 R_E by Sharp et al. (1977) are very narrow, having widths as small as 1° or 2°. The electron beams observed by SCATHA are much wider than this, having half widths of up to 15°. Pitch angle scattering cannot be used to account for this discrepancy because the downflowing electron beams observed by Sharp et al., (1977) are just as narrow as the upgoing beams. Thus it seems likely that the electron beams observed by SCATHA and S3-3 are different phenomena.

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